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## ‘Out of the box’: exploring the 3D modelling potential of ancient image archives

### "Fuera de la caja": explorando el potencial del modelado 3D a partir de antiguos archivos de imágenes

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#### **Resumen**

*La modelización tridimensional dirigida a la investigación y conservación de objetos y yacimientos arqueológicos ha ido cobrando una importancia progresiva, a medida que las técnicas láser y fotogramétricas se han generalizado y simplificado. La gran mayoría de estas técnicas ha sido por el momento aplicada a elementos que pueden ser hoy en día visitados, manejados, medidos y estudiados de diferentes formas. Sin embargo, poca o ninguna atención se ha prestado desde nuestra disciplina al potencial de estos métodos de reconstrucción tridimensional para obtener nuevos datos cuantitativos y cualitativos de elementos destruidos o actualmente inaccesibles. En esta línea, el presente trabajo explora el potencial de la técnica Structure from Motion (SfM) para la explotación científica de archivos de imágenes antiguos. Para ilustrar esta aproximación presentamos aquí dos casos de estudio: la modelización de un ortostato decorado del dolmen de Kermorvan (Le Conquet, Finistère, Francia) a partir de una serie fotográfica de 1911-1912; la modelización de varios elementos de la excavación del túmulo de la Edad del Bronce de Kervingar (Ploudalmézeau, Finistère, Francia), a partir de un video de 12 minutos realizado en 1953.*

**Palabras Clave:** ARCHIVOS DE IMÁGENES, MODELIZACION 3D, STRUCTURE FROM MOTION, HISTORIA DE LA ARQUEOLOGÍA, BRETAÑA, FRANCIA

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#### **Abstract**

*3D reconstructions for research and conservation of archaeological sites and objects are becoming increasingly common as laser and photogrammetric techniques are now more readily accessible to non-specialists. Most of these imaging techniques have been applied to sites and/or objects that can be physically visited, handled, measured and studied in various ways. However, little or no attention has been paid to the potential of modern 3D modelling techniques for obtaining new quantitative and qualitative information from sites and objects which have been destroyed or are no longer accessible. This paper explores the potential of Structure from Motion (SfM) to provide fresh insight into the scientific exploitation of ancient image archives. Two case studies from Western France will be used to illustrate this: a series of photographs of one decorated orthostate from the Neolithic gallery grave of Kermorvan (Le Conquet, Finistère), dating from 1911-12, and a 12-minute video of the excavation of a Bronze Age mound in Kervingar (Ploudalmézeau, Finistère), dating from 1953.*

**Key words:** IMAGE ARCHIVES, 3D MODELLING, STRUCTURE FROM MOTION, HISTORY OF ARCHAEOLOGY, BRITTANY, FRANCE.

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## 1. INTRODUCTION

3D reconstructions for research and conservation of archaeological sites and objects are becoming increasingly common as laser (e.g., LiDAR-TLS) and photogrammetric techniques become more available and feasible to use for non-specialists. In the last few years, several research initiatives have been launched which introduce 3D imaging techniques for architectural analysis (p.e., GILLINGS, 2000), archaeological excavation recording (p.e., DONEUS et al., 2011; DE REU et al., 2013), rock art studies (p.e., SIMPSON et al., 2004; CASSEN et al., 2006), conservation and display of museum collections (p.e., BERALDIN et al., 2000) or heritage vulnerability monitoring and management (p.e., LÓPEZ-ROMERO et al., 2014). The scale of such applications is varied, ranging from the overall record of archaeological sites and buildings, through analysis of specific structures within sites, to the 3D modelling of archaeological objects. Several studies have compared the suitability of two or more imaging techniques for their research purposes; as a result, methodologies are selected carefully and combinations of different techniques are often utilised.

The vast majority of such imaging techniques have been applied to sites and objects that can be visited, measured and studied in several ways. Significantly, one of the most active debates on the use and potential of these techniques deals with the creation of digital archives for preserving and managing cultural heritage.

However, what happens when the elements we aim to study have been lost, seriously damaged or destroyed? Examples might include sites excavated in previous decades or centuries, objects lost from museums and private collections, sites which have been damaged or completely razed through military conflict, or locations threatened by rapid erosion in coastal and island contexts. Surprisingly, to date there has been little consideration of the potential for exploiting existing image datasets to address these losses (but see e.g., GRÜN et al., 2004;

ANDAROODI et al., 2012; DE REU et al., op.cit.: 1114-1116).

With an awareness of the potential of modern imaging techniques and software, we worked on the hypothesis that lost items and sites could be 'reconstructed' from image collections dating from the late-19th and the early-20th century, using available freeware, low-cost software and conventional informatics equipment. We anticipated the process would allow new scientific data to be obtained from old and often undervalued datasets. However, we also expected the results to be limited by the very nature of the inputs, which lack the standardisation required by modern parameters of data capture in 3D modelling.

## 2. THE DATASET. THE ORIGINS OF SCIENTIFIC ARCHAEOLOGICAL RESEARCH IN WESTERN FRANCE

Estimated at more than 70,000 images, the documentary archive of the *Laboratoire d'Anthropologie, Préhistoire, Protohistoire et Quaternaire armoricains* in Rennes, France, created by Pierre-Roland Giot during the 1950s, includes drawings, photographic negatives on plate glass, films, slides, paper photos and several 16mm video recordings. The oldest documents date from the second half of the nineteenth century, and are an exceptional source of information for understanding the emergence of prehistory and archaeology in western France. Most of the early documentary material was generated by the Groupe Finistérien d'Études Préhistoriques (GFEP), established in the 1920s at the Musée de Préhistoire de Penmarc'h (LÓPEZ-ROMERO and DAIRE 2013; DAIRE and LÓPEZ-ROMERO submitted). P.-R. Giot (1919–2002), the last surviving member of this group, preserved the GFEP archives and integrated them into the Laboratoire d'Anthropologie. The dataset was increased by Giot's own research activities, which continued for the entire second half of



the twentieth century, and by the contributions of other researchers.

A significant number of images feature archaeological sites, objects and excavations, with a particular focus on the megalithic monuments of Brittany. The main formats are photographic negatives on plate glass and paper photographs (for earlier documents) and slides (for the more recent). The principal researchers were Geoffroy d'Ault du Mesnil (1842-1921; López-Romero and Le Gall 2008), Alfred Devoir (1865-1923), Charles Bénard (1867-1931), Pierre-Roland Giot (1919-2002) and Jacques Briard (1933-2002).

As some of these researchers (i.e., A. Devoir, Ch. Bénard) were captains and commanders in the French navy, several sets also include materials of a military and expeditionary character. For example, a wooden case contains plate glass negatives recording one of Charles Bénard's expeditions to the Arctic (BÉNARD, 1909; BARR, 1987); this set seems to be complementary to the one preserved in the *Musée d'Ethnographie de l'Université Bordeaux Segalen* (<http://www.meb.u-bordeaux2.fr/>).

Other subjects include the ethnography of rural Brittany, religious architecture, coastal landscapes and geology.

To test the methodology discussed in this paper we used two different sets from these collections: a series of 1911-1912 plate glass photographs by A. Devoir of a megalithic monument in the Conquet region (Finistère) and a 12-minute 16mm film by P.-R. Giot featuring the excavation of a Bronze Age mound in Kervingar (Ploudalmézeau, Finistère), dating back to 1953 (GIOT, 1954).

Alfred Devoir's research on the megalithic monuments of Brittany began around 1890, and was mainly focused in the area of Brest (western Finistère). Among the numerous sites he inventoried and photographed was the Kermorvan gallery grave (allée couverte), which later suffered severe damage during World War II. Some plaster casts of decorated orthostates from the monument, made in 1929 and 1930, still survive (SPARFEL and PAILLER, 2009).

In the case of the Bronze Age mound at Kervingar, the recent rediscovery of a 16mm film dating from September 1953 enabled a review of one of the earliest scientific excavations of the post-war period in Brittany. Even though the site was thoroughly excavated, very few images and detailed plans remain. Extracting new information from the film was particularly relevant as the site constitutes a key milestone in Giot's establishment of the *Laboratoire d'Anthropologie, Préhistoire, Protohistoire et Quaternaire armoricains* in Rennes (LÓPEZ-ROMERO et al., in preparation).

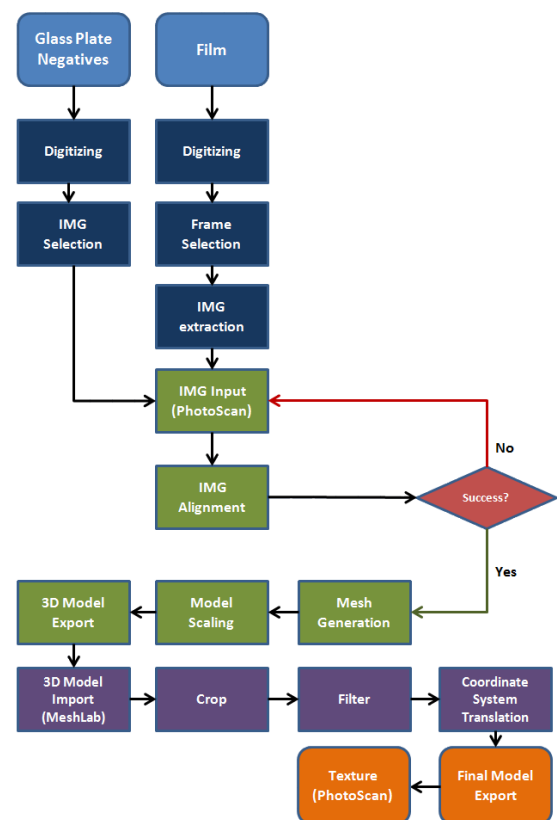


Fig. 1 Process Work Flow

### 3. METHODOLOGY AND ANALYSIS

The methodology comprised the following steps (Fig.1):

- digitisation of the supports and isolation of individual frames from the film;

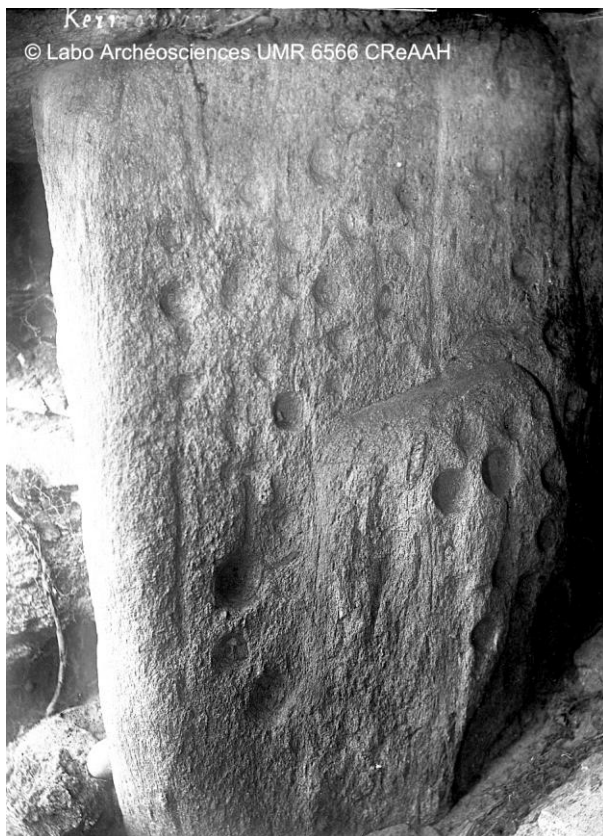


- digital processing of the images;
- post-processing of the resulting 3D models with additional software;
- archaeological and digital analysis of the resulting 3D models.

The final step will be discussed in the Results section.

### 3.1. Digitisation of the supports and isolation of individual frames from the film

The 1911-1912 black-and-white photographic glass plate negatives measure 9 x 12cm (Fig.2).



*Fig. 2 Decorated orthostate from the Neolithic gallery grave of Kermorvan in 1912, by A. Devoir. © Labo Archéosciences UMR 6566 CReAAH*

They are dry plates made by silver gelatine emulsion; however information on the camera model or shooting parameters is lost. Like most images from the documentary archive in Rennes, they were scanned on a conventional

flat-bed scanner as 600ppm JPG RGB files. The decision to use JPG rather than uncompressed or lossless compression raster formats was taken in 2008 as a temporary solution in response to the urgent need to preserve the archive, constrained by limited server space and a lack of full-time dedicated staff. The most suitable images were carefully selected after the scanning process. Finally, 10 of the original 24 images of the decorated orthostates from Kermorvan gallery grave were chosen for analysis. File sizes ranged from 804KB to 1.124KB.

The procedure for the film was different. The film was originally made with a Pathé Webbo Super 16 camera equipped with three different lenses (1.8/20mm; 1.9/28mm; 3.5/50mm). Due to its condition and nature, in 2011 the professional agency Génération Vidéo (<http://www.generation-video.fr/>) scanned the original 12-minute film along with other 16mm films by Giot dating from 1952 to the 1970s. A VOB file (Video Object-VOB) was produced as a result of this process. As it was originally filmed with a hand-held camera, a significant amount of photograms are blurred and unusable due to rapid camera movements. Therefore, it was necessary to extract the best quality images for analysis frame by frame. This was achieved with the open source software Video LAN-VLC Media Player. Each image was saved as an individual PNG file (Portable Network Graphics), with a final dimension of 768 x 576 pixels and a low file size of between 441KB and 661KB.

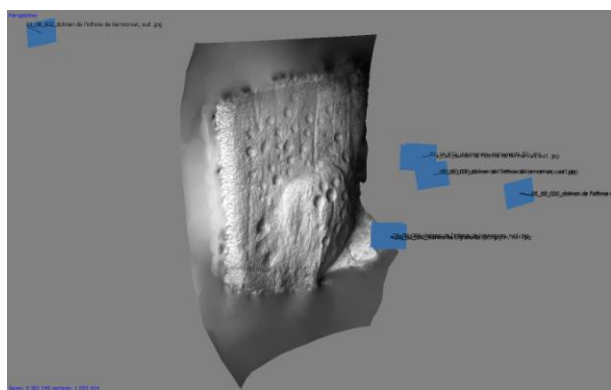
There was no manipulation of the images (i.e., cleaning, filtering, etc.) after the initial scan.

### 3.2. Digital processing of the images

The resulting digital images were loaded in Agisoft Photoscan Professional 0.9.1. software. The digital processing of the files was performed using an Acer Aspire V3-771G computer, equipped with an Intel® Core™ i7-3632QM 2.2GHz processor and NVIDIA® GeForce® GTX 730M graphics. In order to create the 3D models, the usual Photoscan workflow was followed



(<http://www.agisoft.ru/tutorials/photoscan>). In the absence of precise camera parameters (as was the case with our examples) the software assumes a focal lens value of 50mm in an attempt to align the images. Automatic alignment of the 10 selected images of orthostate no.5 from Kermorvan was successful, and a point cloud with the matching points in the images was obtained. In order to minimise the errors associated with the alignment process, a filtering of points with high reprojection error (above a 0.48 threshold) was performed. Model geometry was then built, resulting in a first 3D surface (Fig.3).



*Fig. 3 Decorated orthostate from the Neolithic gallery grave of Kermorvan: camera alignment and 3D surface in Agisoft Photoscan Professional 0.9.1.*

Unlike other images from the site, no graphic scale was present in the set depicting orthostate no.5. However, in his publication of the monument, Alfred Devoir specifies the diameter and depth (60 x 35mm) of one particular cup-mark in the stone surface (DEVOIR, 1912). Further measurement information was obtained from a later sketch by E. Morel published in 1929 (BÉNARD, 1929: 253). Even though these measurements may prove inaccurate they were used to scale the model. In order to show that modelling and scaling could be achieved using original images and source documents only, we chose not to take measurements from the plaster cast of this orthostate held by the Musée de Préhistoire de Penmarc'h.

Three models were obtained from the Kervingar film. Of the three dry-stone walling cists excavated only Tombe A (two models from two different stages of the excavation process) and Tombe C (one model showing the northern end of the chamber) were successfully partially reconstructed. Tombe A is the most documented element in the film; it was recorded from three different perspectives, one being a close and detailed view of the stone setting that configures the outer cairn. Conversely, Tombe C was rarely recorded; this resulted in few good quality images for analysis, and some blurred frames were included to facilitate the model reconstruction. The procedures were the same as for Kermorvan, although the presence of ranging poles as scales permitted more accurate scaling of the models.

The details of the various modelled surfaces are summarized in Table 1.

SITE	STRUCTURE	DESCRIPTION	INPUT IMG	IMG ALIGNED	MODEL FACES (undecimated)	Filter steps (Depth Smooth)
Kermorvan gallery grave	orthostate no.5	Decorated orthostate	10	10	3.3M	-
Kervingar	Tombe A	Excavation phase1	49	49	820.000	-
Kervingar	Tombe A	Excavation phase2	21	21	580.000	-
Kervingar	Tombe C	Excavation phase2	29	25	1.17M	25

*Table 1 Models summary*

After scaling, the models were exported as PLY (Stanford Polygon File Format).

### 3.3. Postprocessing of the resulting 3D models

PLY files were imported in MeshLab software. They were edited for residual polygon and vertex removal. In the case of Tombe C, a depth smooth filter (25 steps) was applied to the model in order to improve its visualisation.

In the absence of an absolute coordinate reference system every model was translated to a relative position reference system, aligning it to one of its principal axes. In the case of

Kermorvan the frontal, flat, decorated surface was taken as the X/Y reference, while the depth (e.g., cup-marks) provided the Z reference. In the case of Kervingar, the width of the excavation profiles where the structures were embedded (East profile of the north-eastern quadrant for Tombe A, South profile of the south-western quadrant for Tombe C) was taken as the X reference, the height from the terrain surface to the excavation baseline was used as the Y reference, and the perpendicular axis to them provided the Z reference.

Once these modifications were saved, the resulting models were exported again as PLY files and imported in Photoscan. A photorealistic texture was then applied to them using the original input images (Fig.4).

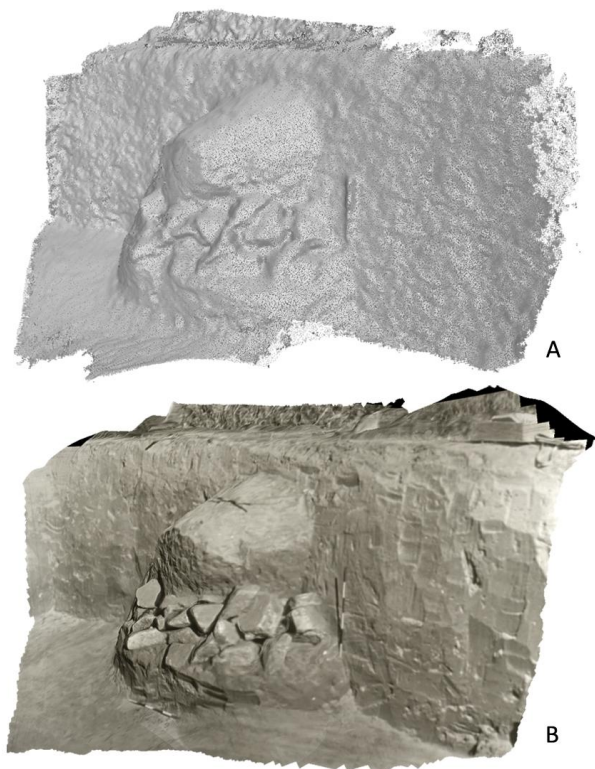


Fig. 4 Kervingar 'Tombe A'. Dense Point Cloud (A) and textured 3D model (B) of the first phase of the excavation. Film © Labo Archéosciences UMR 6566 CReAAH

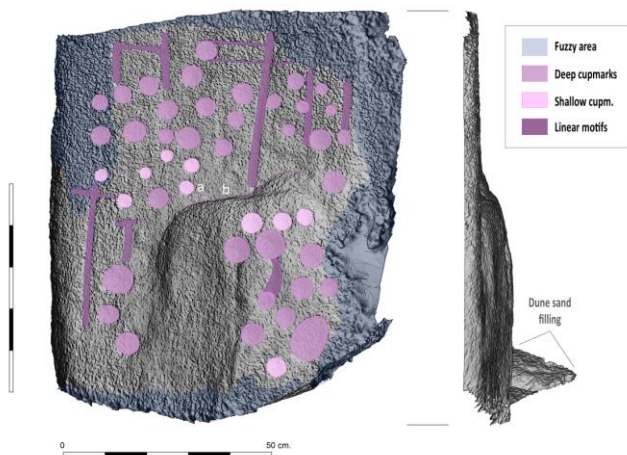
## 4. RESULTS

The different 3D models have been the object of different kind of analyses.

The main source of interest in the study of Devoir's 1911-1912 plate glass photographs are the motifs engraved in Kermorvan gallery grave. Obtaining precise records of these motifs is a key step towards understanding the architectonic and symbolic significance of the monuments.

Several drawings of the carvings from Kermorvan have previously been published, with a particular focus on orthostate no.5. Some examples were drawn from the original monument, such as those produced in 1903 by P. du Chatellier (1833-1911), in 1912 by A. Devoir and around 1929 by E. Morel; others were obtained in 1997 and 2008 from the plaster casts in the Musée de Préhistoire de Penmarc'h, made in 1929 and 1930 (v. SPARFEL and PAILLER, 2009: 188, figure 203). While the first group of drawings records the overall shape of the orthostate they are not accurate; the latter depict only the area containing the carvings. In order to test the potential of SfM to contribute to the study of destroyed or damaged objects, we obtained new drawings of the carvings from the 3D model of Kermorvan's orthostate no.5. We adapted the methodology currently applied to megalithic art (e.g., CASSEN and VAQUERO, 2003), substituting direct lighting of the real stone surface for artificial lighting of the model surface. The un-textured surface was illuminated from eight different positions (using both single-side and double-side lighting) with MeshLab software. A 2D TIFF (Tagged Image File Format) image was exported of each lighting position. The TIFF images were then integrated into a single multi-layer PSD (Adobe Photoshop) file. The carvings visible in each image were traced manually and stored as separate vector layers in the PSD file. These vector layers were finally superimposed to obtain a graphic synthesis and a final interpretive synthesis of the carvings (Fig.5).





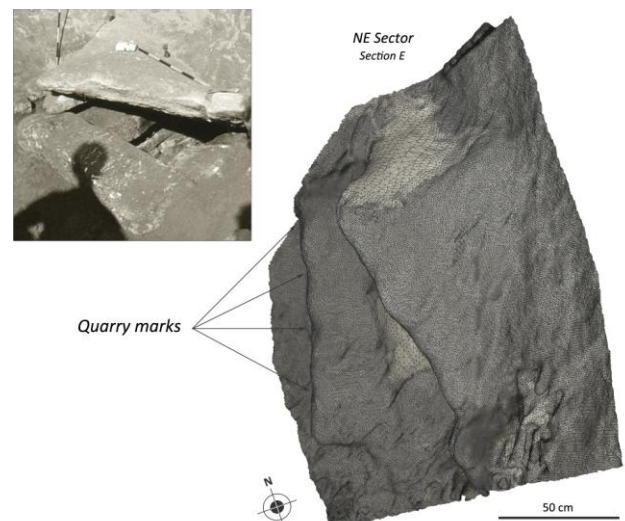
*Fig. 5 Interpretive synthesis of the carvings in Kermorvan's orthostate no.5. The cup-mark 'a' and the linear motif 'b' are not represented in previous depictions of the orthostate*

In the case of the Kervingar mound, the film and 3D models extracted from it provide new insights into the excavation process as well as the characteristics of some of the structures. The procedures for clearing and opening the three funerary chambers within the mound appear largely conditioned by the specific methodology chosen for the excavation (quadrants and baulk sections, adapted from the methodology of Dutch archaeologist Albert Van Giffen, 1884-1973). As a result of the use of this methodology the funerary chambers were embedded into the stratigraphic sections, making access to them difficult to the excavators. The exposed wall of each tomb was then dismantled. In the case of the northern chamber (Tombe A), a sedimentary layer covering the stone-built structure was initially visible but was then removed by the excavators prior to accessing the chamber. The stones of the outer cairn were originally built following a ring-shaped pattern, and a large (c. 1.25 x 0.35m) lintel-shaped slab was set at the top of the western wall; this slab appeared to be a very specific structural element of the northern cist. Visual analysis of the 3D model of this architectural element has also allowed us to identify several extraction marks on the slab (Fig.6). These marks were completely invisible in the film and in the few unpublished photographs preserved from the excavation;

they have been revealed only by manipulation of the 3D model. Similar marks seem to be present on the covering slab of Tombe C, although they are much less apparent (Fig.7).

Unfortunately, we were unable to successfully model the central structure (Tombe B) or other features such as a layer of scattered stones from the SW quadrant of the excavation, the interpretation of which remains uncertain.

A more detailed account of the film contents and of the scientific context of the excavation is in preparation (LÓPEZ-ROMERO et al., in preparation).



*Fig. 6 Kervingar 'Tombe A'. 3D model of the funerary cist showing the quarry marks in one of the slabs. Second phase of the excavation. Film © Labo Archéosciences UMR 6566 CReAAH.*



*Fig. 7 Kervingar 'Tombe C'. 3D model of the funerary cist. Film © Labo Archéosciences UMR 6566 CReAAH.*



## 5. DISCUSSION AND CONCLUSIONS

In this paper we have explored what we consider to be one of the most promising applications of modern 3D imaging techniques: the recovery from ancient image archives of new scientific and metric information about lost sites and objects. For this we have used conventional hardware equipment, open-source (i.e., MeshLab, Video LAN-VLC Media Player), medium-cost (i.e., Agisoft Photoscan) and commercial (i.e., Adobe Photoshop) software.

Despite numerous problems around the quality and quantity of our input data, we have successfully generated measurable 3D models from images dating from 1911, 1912 and 1953. In complement to their inherent value as visual records of the past, these new models have allowed us to extract fresh scientific information from archaeological sites and structures that have been destroyed, seriously damaged or are no longer accessible.

As we have seen, success in modelling is largely conditioned by the nature of the inputs. Even though certain image analysis protocols and stereo cameras have been in use since the late-19th century, the images contained in the early archives of archaeology were not intended for the types of analysis discussed here. The images do not fulfil most of the criteria for modern 3D modelling techniques. The main limitations we have encountered to modelling 3D surfaces from these datasets are:

- there may be few images available of the objects or structures of interest;
- multiple perspectives of the objects are rare (insufficient views from different angles/positions);
- lighting of the subjects is often inappropriate (areas in shade or overexposed will not be correctly modelled);
- precise camera and image parameters may be absent;
- metric scales for some objects/structures are lacking;

- relative coordinate systems must be used;
- in the absence of ground control points (GCP), it is difficult to evaluate the accuracy of the model.

Most of these problems are common to later 20<sup>th</sup>-century datasets obtained with analogue non-metric cameras (v. GRÜN et al. op. cit.: 183-184).

When it is impossible to return to the real object to validate our observations there is a risk of over- or mis-interpretation of the information visible in the model. Similarly, the modelled surface may not include subtle elements that were actually present on the surface of the object being studied (e.g., fine incisions). While in some instances it might still be possible to interpret through comparison of the results with other sources (e.g., Kermorvan orthostate no. 5; Fig.5, 'a' and 'b'), in most cases the synthesis obtained from the model will be the only available record and will always retain a degree of uncertainty. The higher the quality, coverage and variety of the input images, the better the quality of the modelled surface and the lower the risk of mis-interpretation.

When successful, this surface reconstruction facilitates the study of new quantitative (e.g., measurements, volumes) and qualitative (e.g., identification of new items) data that would otherwise have remained unavailable. Key achievements have been proposing a new and contextual depiction of the engravings from Kermorvan's orthostate no.5, retracing some excavation procedures at Kervingar (Tombe A) and identifying relevant characteristics of the technological processes involved in constructing the cists (i.e., shape, measurement and quarrying/extraction marks on the lintel-shaped slab in Tombe A; potential quarrying/extraction marks on the covering slab in Tombe C). This kind of analysis offers a key tool to help validate current hypotheses on the space, architecture and technology of destroyed or inaccessible archaeological sites (e.g., LARGE, 2013).

The application of this analytical perspective to other datasets will provide further insights into its accuracy, limitations and potential. Above all, these techniques should serve to revitalise the

study of ancient image archives, to date limited by their two-dimensionality, renewing their value as primary sources for the study of the past.

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